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INITIAL EXPLORATION OF JAMMING METHODS ASSOCIATED
WITH SYNTHETIC APERTURE RADAR

by

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INITIAL EXPLORATION OF JAMMING METHODS ASSOCIATED WITH SYNTHETIC APERTURE RADAR

Hu Yongfu Zhao Shuyuan

Translation of "He Cheng Kong Jing Lei Da De Gan Rao Fang Fa Chu Tan"; pp 170-175

ABSTRACT Setting out from the processes associated with SAR signal processing, this article discusses SAR processing gains with regard to target echoes and different types of jamming signals. In conjunction with this, influences of different types of jamming signals on SAR are elucidated on this basis, studying jamming methods with regard to SAR.

KEY WORDS Synthetic aperture radar Jamming

I. INTRODUCTION

Synthetic aperture radar (SAR) technology is a type of radar technology system which was developed beginning in the 1950's in order to satisfy military requirements. Come the 1970's, there were breakthroughs in key technologies, causing SAR technology to experience very great development. In early SAR applications to military affairs, the primary use was in strategic intelligence reconnaissance. Due to the fact that SAR possessed such advantages as high resolution, strong penetration capabilities, good signal to noise ratios, and so on, tactical military applications of SAR were searched for right along. Since the 1980's, due to the fact that the development of signal processing technologies has caused the volumes and weights of SAR signal processing equipment to already very, very greatly decrease, in this way, it has then made SAR tactical applications become possible. At the present time, outside China, option has already been made for the use of SAR to act as reconnaissance and aiming radars for such systems as fighter

bombers, and so on. The newest generation of missile homing devices has also begun to opt for the use of SAR. Due to the fact that SAR possesses comparatively high counter jamming capabilities compared to conventional radars as well as relatively low probabilities of being acquired by reconnaissance, it is predicted that from now on tactical applications of SAR will expand step by step. The threat it poses will get larger and larger. As a result, there is a need to study problems associated with how to carry out jamming with regard to SAR in order to search out jamming methods that are practically feasible.

II. BASIC OPERATING PRINCIPLES OF SYNTHETIC APERTURE RADAR

Speaking in simple terms, SAR is nothing else than the making use of an actual small dimension antenna to emit on flight paths, receiving and storing ranges and phases associated with echo signals for a certain specially designated target. After obtaining sufficient numbers of echoes, signal processing is carried out on them to obtain an equivalent large dimension antenna. A typical simplified line and block chart for SAR principles is as follows.

High Frequency Portion-->Range Selection-->Phase Detection-->Compression Network-->Display

Assuming that the radar emission signal frequency is f, then, the echo signal frequency received by radars is $f+f_d$. In this, f_d is the Doppler frequency produced because of relative motion between targets and radars. Making use of range selection devices, range selection is carried out with regard to required target echoes. Phase detectors carry out beats with respect to received signals and stable reference signals to obtain linear frequency modulation signals associated with null center frequencies. They include target angular location information. Compression networks take Doppler frequency modulation signals and compress them into a

narrow pulse in order to form range compressions and azimuth compressions. In this way, signals are then obtained associated with different ranges and different bearings. /171

During SAR signal processing, it is first of all necessary to carry out compensation calibration with regard to echo signal phases, causing the phases of echo signals reflected from the same target in each iteration of emissions to be the same--thus, guaranteeing to make echo signals associated with targets maximal. Due to the fact that SAR requires the carrying out of phase compensation, as a result, the emitted signal frequencies are generally very stable.

III. FUNCTIONS ASSOCIATED WITH SAR PROCESSING OF SIGNALS AND NOISE (OR JAMMING)

SAR handling processes can be expressed by the use of the mathematical model set out below.

```
RF Filter-->Range Processing-->Doppler Filter-->Azimuth-->
  (Br)        τ tBr: nr              Bd         Processing
                                                    n
```

Range processing generally opts for the use of chromatic dispersion delay lines to carry out pulse compression or opts for the use of correlation processing or FFT processing, thus forming compressed narrow pulses in terms of range. Azimuth processing uses echo signals received within a synthetic aperture length to carry out vector addition, thereby realizing azimuth compression.

1. Making Use of Chromatic Dispersion Delay Lines to Carry Out Range Compression Processing

(1) Signal Processing Gains

Assuming that delay lines have no energy losses, the overall energy of signals does not change before or after, that is, $S_1 \tau_t = S_r \tau_C$

$S_r = S_1$ (τ_t/[illegible] τ_C) = S_1 ($\tau_t B_r$)

(2) Processing With Regard to Thermal Noise

Chromatic dispersion delay lines carry out sampling in respect to thermal noise. If consideration is only given to a single thermal noise sample width, then, after going through processing, the actual electric power level within a resolution element will drop to be one part of range compression ratios associated with input noise power. However, due to the fact that thermal noise is continuous and random, it is equivalent to the carrying out of repeated samplings with regard to thermal noise. In this way, all sampling noise powers carry out addition with each other. As a result, the total noise power do not vary before and after processing, that is, $N_r=N_1$.

(3) Processing With Regard to Jamming Signals

Speaking in terms of SAR, if jamming signals are noncoherent, then, the effects of range compression processing on them will be the same as for thermal noise, that is, $J_r=J_1$.

If jamming signals and SAR range compression networks are matched, then, the effects of range compression processing on them are then the same as for target echo signals, that is, $J_r = J_1 (B_r \tau_t)$.

2. Making Use of Correlation or FFT Processing to Carry Out Range Compression Processing

(1) Processing of Signals

Correlation processing and FFT are capable of being seen as vector additions of n individual signals. It is possible to believe that echo signals are in phase signals. The ranges of summation signals obtained by vector addition are the sum of ranges associated with various input signals. Powers are square multiples of scaler quantities associated with added signals.

$$S_r = S_1 n^2{}_r = S_1 (B_r \tau_t)^2$$

(2) Handling of Thermal Noise

Due to the fact that thermal noise is noncoherent, as a result, multiples of increase associated with noise powers after correlation processing are processed noise sampling numbers, that

is, $N_r = N_1 n_r = N_1 (B_r \tau_t)$. /172

(3) Processing of Jamming Signals

In the same way, it is possible to obtain jamming signal powers associated with noncoherent jamming signals and coherent jamming signals as being, respectively:

$Jr = J_1 (B_r \tau_t)$; or, $J_r = J_1 (B_r \tau_t)^2$.

3. Azimuth Compression Processing

The basic nature of azimuth compression processing is to take n iterations of sampling signals on a synthetic aperture length and carry out vector addition. Echo signals associated with the same target in different sampling periods become in phase signals after going through phase compensation. As a result, target signal powers after azimuth compression processing will increase n^2 times, that is, S(illegible) = $S_1 n^2$.

In the same way, with regard to thermal noise and noncoherent jamming signals, due to the fact that it is not possible to maintain phases associated with the intervals between various samplings the same, as a result, powers after processing are only able to increase n times, that is: N(illegible) = $N_1 n$ and J(illegible) = $J_1 n$.

4. Calculations of Signal to Jamming Ratios

In order to facilitate description, assume that jamming signals enter from the direction of SAR main beams. In conjunction with this, ignore the influences of jamming signal frequency mismatch. A certain amount of jamming signal enters from auxiliary lobes or existing frequency mismatches. The influences are equivalent to lowering effective jamming power.

Signal to noise ratios associated with single pulses are:

$$(S/J)_1 = (P_t G_t / P_j G_j) \cdot (R_j^2 / 4\pi R_t^4) \sigma \qquad (1)$$

If option is made for the use of noncoherent jamming, then, signal to jamming ratios after going through SAR processing are:

$$(S/J)_{ra} = (S_{ra} / J_{ra}) = (S/J)_1 \cdot (n B_r \tau_t) \qquad (2)$$

Certain jamming signals are matched with SAR range compression networks. However, phases between various iterations of emission periods are not coherent. By contrast, in the same way as range processing with regard to jamming and echo signals, only azimuth processing is able to increase signal to jamming ratios, that is:

$$(S/J)_{ra}=(S/J)_i \cdot n \tag{3}$$

If jamming signals are matched with both SAR range compression and azimuth compression networks, then, range compression processing and azimuth compression processing are the same in both cases with regard to jamming signals and echo signals. Signal to jamming ratios are maintained invariable before and after processing:

$$(S/J)_{ra}=(S/J)_i \tag{4}$$

Assume that flight velocity is v, synthetic aperture length is L, and SAR pulse repetition frequency is PRF. Then, n=PRF(L v). If the linear azimuth resolution (lateral range resolution) required by SAR is w, the, $w = R_t \ (\lambda/2L)$

$$n=PRF(R_t \lambda/2wv) \tag{5}$$

IV. INQUIRY INTO METHODS OF JAMMING SAR

SAR requires preserving the phase and range of target echo signals. Only in this way is it possible to carry out range compression and azimuth compression processing, afterwards obtaining location information associated with targets. If errors exist in the phases and ranges associated with echo signals, in that case, there will then be influences with regard to target resolution. No matter whether SAR is used in photographic reconnaissance or used in carrying out search and tracking with regard to targets, if it is not able to resolve targets well, the effects of its utilization will then be subject to influences. As a result, with regard to the jamming of SAR, considerations are still the same as conventional radar. Starting out from signal to jamming ratios, consideration is given to the effects of various types of jamming signals on SAR.

1. Covering Jamming /173

Covering jamming is making use of noise or signals like noise in order to conceal target echo signals, thus making radars have not way to discover targets. As a result, jamming signals--speaking in terms of SAR--are noncoherent. The signal to jamming ratios are precisely determined from equation (2). Making use of equalities (1), (2), and (5), it is possible to obtain:

$$(S \cdot J)ra = (P_t G_t \tau_t PRF\ P_j G_j) \cdot (R_j^2 \cdot 4\pi R_t^3) \cdot (\lambda \sigma B_r\ 2wv) \quad (6)$$

SAR signal to jamming ratios during covering jamming form inverse proportions with the cube root of radar and target distances (and are not the normal fourth root in radars). Direct proportions are formed with range compression ratios and azimuth compression ratios. The explanation is that, when jamming conditions are the same, the SAR region that is subject to jamming will be smaller than that associated with ordinary radars.

(1) Barrage Jamming

Jamming band widths during barrage jamming are far, far wider than SAR radio frequency band widths. As a result, there exist frequency spectrum mismatch problems. Jamming signals only play a role within SAR radio frequency band widths. This is equivalent to lowering the effective jamming power of jammers. Jamming noise is distributed within the entire range band widths of radars and possible Doppler frequency ranges. Effects in SAR are like thermal noise. As a result, after going through processing, jamming signals will form "spots" on SAR displays. In terms of ranges and azimuths, it is continuous. It is only effective when it reaches a certain jamming intensity. The size of the region subject to jamming is calculated from signal to jamming ratio formulae and frequency spectrum mismatch.

(2) Aimed Jamming

The band width associated with aimed jamming lies within the SAR reception band width. Frequency spectrum mismatch problems do not exist. However, due to the fact that jamming signals are narrow band noise, they are not able to be completely identical

with Johnson noise. Range compression processing is not capable of completely compressing it. In the end, the "spots" that are formed on SAR displays show some expansion in the direction of range. Jamming is still continuous in range and azimuth.

Jamming signal modulation methods will also have a certain influence on jamming effects. Direct radio frequency noise and frequency modulation noise jamming signals can be seen in SAR as acting as a uniform range weighted noise. As a result, the "spots" formed by jamming in regions subject to jamming are uniform. Amplitude modulated noise jamming can be seen in SAR as acting as a nonuniform range weighted noise. As a result, the size and mottling of the "spots" formed by the jamming change to a certain degree. However, due to the accumulated effects associated with the existence of multiple iterations of observations, this type of change will tend to flatten out.

If option is made for the use of pulse type jamming and if jamming is synchronous, then, various iterations of jamming lie on the same SAR range unit. If jamming is nonsynchronous, then, jamming lies within the entire SAR range. During pulse jamming, even if effective jamming powers decrease, the jamming status is similar to that during aimed jamming. However, due to the fact that the number of iterative samples is reduced, the smoothing effects associated with multiple iterations of observations will not be very obvious.

2. Deception Jamming

The purpose of deception jamming is the production of false signals on radars. It is possible to opt for the use of two types of implementation methods--repeating methods and response methods.

(1) Repeating Methods

Repeating jamming is--following reception of radar signals--immediate transmission (or after delay of a certain time period) of jamming signals, after going through amplification. Due to the fact that jamming signals are obtained from received radar signals, as a result, it is possible to maintain certain characteristics of the original radar signals.

a. If repeating jamming is capable of simultaneously preserving internal radar signal pulse characteristics (for example, pulse width, band width, as well as FM slope, and so on) and interpulse characteristics (that is, the phases of various iterations of repetition), then, SAR processing of jamming signals is the same as echo signals--that is, range compression and azimuth compression processing will cause jamming signals and echo signals to increase by the same sorts of multiples. Signal to jamming ratios are given by equation (4).

$$(S/J)_{ra} = (S/J)_1 = (P_t G_t / P_J G_J) \cdot (\tag{7}$$

Signal to jamming ratio formulae are completely the same as for ordinary radars. The explanation for this is that SAR processing at this time is certainly not able to improve SAR counter jamming performance. This is because jamming signals make use of radar signal coherence properties, causing SAR, in reality, to have no way of distinguishing jamming from echo. Jamming signals are point targets on SAR displays. The locations are determined by the actual positions of jammers and delay times associated with repeating jamming. Jamming signal intensities also increase multiples associated with azimuth compression ratios and range compression ratios. As a result, strengths are very great. Due to the fact that SAR possesses very high processing gains with regard to this type of jamming signal, for that reason, there is a possibility to make jamming go through radar antenna parasite lobes enter into radars. /174

b. If repeating jamming is only able to preserve internal pulse characteristics associated with radar signals, then, jamming signals in range compression processing are coherent. However, in azimuth compression processing, they are noncoherent. Signal to jamming ratios at this time are precisely determined by equation (3).

$$(S/J)_{ra} = n(S/J)_1 = (P_t G_t PRF / P_J G_J) \cdot (R_j^2 / 4\pi R_t^3) \cdot (\lambda \sigma / 2wv) \tag{8}$$

Signal to jamming ratios at this time form inverse proportions with the cube root of Rt, only forming direct proportions with azimuth compression ratios. Jamming signals on SAR displays are still a

point target. However, in terms of azimuths, they are widened out into circular arcs.

c. If repeating jamming is not capable of preserving radar signal characteristics, then, SAR processing of it will be the same as covering jamming. Signal to jamming ratios increase range compression ratio and azimuth compression ratio multiples. On SAR displays, jamming undergoes expansion in terms of both range and azimuth.

(2) Response Jamming

Response jamming signals are certainly not associated with the carrying out of direct amplifications of received radar signals, but are jamming signals obtained by the use of such methods as storage frequencies, and so on. Strictly speaking, jamming frequencies will not be the same as radar signals. However, if jamming frequencies are very stable, then, it is possible to believe that frequencies associated with jamming signals in periods of two iterations of emissions do not change. As a result, the jamming effects are similar to quasi coherent repeating jamming. Due to the fact that response jamming is the retransmission of jamming associated with the storage of received radar signals after going through a period of time, if it is possible to measure SAR repetition frequencies, it is then possible to make jamming signals arrive at radar receivers ahead of echo signals. Going through changes in delay periods associated with jamming emissions, it is then possible to use jamming to create false targets controlled within a certain range of distances. Besides this, with regard to echo signals associated with a certain specially designated target, the phase changes associated with them in time periods for two iterations of SAR emissions have a definite pattern to them. Due to the fact that different phases stand for different target azimuths, as a result, if it is possible to carry out a quantitatively fixed phase shift in jamming signals during the emission of response jamming, in that case, it is then possible to make the azimuths of false targets also have a certain range of changes. Carrying the inference a step further, assume that, after

storing up one iteration of received radar signals, if it is possible during the period of the next radar emission to send out multiple iterations of jamming in accordance with different delays and phase shifts, it is then possible, on SAR displays, to form multiple false targets. The results are equivalent to increasing the numbers of jammers.

3. Passive Jamming

Passive jamming methods have results with regard to SAR which are the same as for ordinary radars.

4. Examples

Assume that the frequency of a certain airborne SAR is 10GHz. Transmission peak value powers are 50kW. Antenna gain is 30dB. Parasitic lobe electric level is -30dB. PRF is 1500Hz. Pulse width is 10μs. Receiver band width is 10MHz. Range compression ratio is 100. Azimuth resolution is 30 meters. Aircraft speed is 30m/sec. At present, it is prepared to carry out search and aiming against a radar reflection area that is 1000 square meters and a target of 10 square meters. Jammers are deployed in the vicinity of the protected target (that is, jamming range is equal to target range). Radar effective search and jamming range is 80-20 thousand meters. When jamming signals are 5dB higher than target echoes, it is possible to believe that jamming is effective. Making use of equations (6), (7), and (8), respective calculations are made when effective jamming is carried out at locations of 80, 40 and 20 thousand meters (corresponding azimuth compression ratios are, respectively, 200, 100, and 50). Effective jamming powers $P_J G_J$ required when option is made for the use of main lobe jamming and parasitic lobe jamming are shown as subscripts.

Effective radiated powers associated with surface-air radar jammers which are currently on hand are on the order of 1MW. From the table it can be seen that, opting for the use of jamming that is coherent both inside pulses and between pulses (can be realized using repeating jamming) to suppress radars, the required jamming

powers are very easily satisfied. Opting for the use of jamming that is only coherent inside pulses (can be realized using repeating and response jamming)--except for when large model targets are protected by means of ways associated with intermediate range and close range jamming through parasitic lobes--in other situations, the jamming power requirements necessary can all be satisfied. During noncoherent jamming (ordinary covering jamming), main lobe jamming can be used to protect small model targets as well as comparatively large targets at intermediate ranges and long ranges. Parasitic lobe jamming is only capable of protecting small model targets at intermediate ranges and long ranges. /175

V. CONCLUSIONS

Due to the special signal processing methods associated with SAR, it causes SAR to possess counter jamming capabilities which are higher than ordinary radars. However, SAR can still be jammed. When option is made for the use of covering jamming, due to the fact that the jamming powers required are very high, only main lobe jamming power requirements can possibly be realized. As a result, it can be believed that this type of jamming is not feasible during actual combat. Repeating jamming, which maintains radar signal characteristics inside pulses and between pulses, possesses very great advantages in terms of jamming power requirements. It is also possible, through radar antenna parasitic lobes, to jam radar operations. As a result, it is the comparatively advantageous method to carry out jamming against SAR.

		脉内脉间均相干		脉内相干脉间非相干		脉内脉间均不相干	
		主瓣干扰	副瓣干扰	主瓣干扰	副瓣干扰	主瓣干扰	副瓣干扰
80 千米	1000	1.866 W	1866 W	373 W	373 kW	37.3 kW	37.3 MW
	10	0.0186 W	18.6 W	3.73 W	3730 W	373 W	373 kW
40 千米	1000	7.47 W	7470 W	747 W	747 kW	74.7 kW	74.7 MW
	10	0.075 W	75 W	7.47 W	7470 W	747 W	747 kW
20 千米	1000	29.85 W	29.85 kW	1493 W	1493 kW	149.3 kW	149.3 MW
	10	0.299 W	299 W	14.93 W	14.93 kW	1493 W	1493 kW

(1) Thousand Meters (2) Coherent Both Inside and Between Pulses (3) Coherent Inside Pulses Noncoherent Between Pulses (4) Noncoherent Both Inside and Between Pulses (5) Main Lobe Jamming (6) Parasitic Lobe Jamming

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